CEBAF PROPOSAL COVER SHEET

A. TITLE: A Longitudinal-Transverse Separation of the Amplitudes for the $S_{11}(1535)$ Resonance

B. CONTACT PERSON

K. Giovanetti
Physics Department
James Madison University
Harrisonburg, VA 22807
703-568-6353

FACK_GIO@JMUVAX1

S. Dytman
Physics Department
University of Pittsburgh
Pittsburgh, PA
412-624-9244

DYTMAN@PITTVMS

C. THIS LETTER OF INTENT IS BASED ON A PREVIOUSLY SUBMITTED LETTER OF INTENT

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A Longitudinal-Transverse Separation of the Amplitudes for the $S_{11}(1535)$ Resonance

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contact. Giovanetti

Study of Electromagnetic Excitation of Baryon Resonances with the CEBAF Large Acceptance Spectrometer

The N* Collaboration

V. Burkert, D. Joyce, B. Mecking, M.D. Mestayer, B. Niczyporuk, E.S. Smith, A. Yegneswaran
CEBAF, Newport News, Virginia

R. Minehart, D. Day, J. McCarthy, O. Rondon-Aramayo, R. Sealock, S. Thornton, H.J. Weber
University of Virginia, Charlottesville, Virginia

P. Stoler, G. Adams, L. Ghedira, N. Mukhopadyay
Rensselaer Polytechnic Institute, Troy, New York

R. Arndt, D. Jenkins, D. Roper
Virginia Polytechnic Institute and State University, Blacksburg, Virginia

D. Isenhower, M. Sadler
Abilene Christian University, Abilene, Texas

D. Keane, M. Manley
Kent State University, Kent, Ohio

S. Dytman, T. Donoghue
University of Pittsburg, Pittsburg, Pennsylvania

C. Carlson, H. Funsten
College of William and Mary, Williamsburg, Virginia

D. Doughty
Christopher Newport College, Newport News, Virginia

L. Dennis, K. Kemper
Florida State University, Tallahassee, Florida

K. Giovanetti
James Madison University, Harrisonburg, Virginia

J. Lieb
George Mason University, Fairfax, Virginia

W. Kim
University of New Hampshire, Durham, New Hampshire

C. Stronach
Virginia State University, Petersburg, Virginia

M. Gai
Yale University, New Haven, Connecticut

Proposal 5

A Longitudinal-Transverse Separation of Amplitudes for the $S_{11}(1535)$ Resonance

The N*-Collaboration

G.Adams, R.Arndt, V.Burkert, C.Carlson, D.Day, L. Dennis, T.Donoghue, D.Doughty, S. Dytman, H.Funsten, M.Gai, L.Ghedira, K.Giovanetti, D. Isenhower, D. Jenkins, D.Joyce, D.Keane, K. Kemper, W.Kim, J. Lieb, M.Manley, J.McCarthy, B.Mecking, M.Mestayer, R.Minehart, N.Mukhopadyay, B.Niczyporuk, O.Rondon-Aramayo, D.Roper, M. Sadler, R.Sealock, E.Smith, P.Stoler, C.Stronach, S.Thornton, H.Weber, A.Yegneswaran

Spokesmen: K. Giovanetti and S. Dytman

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ABSTRACT

We propose to measure the longitudinal contribution to the electroproduction of the $S_{11}(1535)$ resonance as a function of Q^2. The properties of the S_{11} form factor provide excellent evidence for the breakdown of SU(6) symmetry. We propose this case because in addition to its interesting physics properties, the S_{11} has a large production cross section and is easily identified through the ηp decay channel. Because all resonances are predominantly excited by transverse photons, an absolute accuracy of a few percent will be required. Given the design goals of the CEBAF electron beam and the proposed CLAS detector we expect to be able to measure total cross sections with a few percent accuracy and extract the ratio R (σ_L/σ_T) with an error of $\pm.05$. With such stringent requirements, this experiment should run in the 2^{nd} round of CLAS experiments.

INTRODUCTION

Improving our knowledge of the nucleon resonances will provide insight into the underlying structure of the quark-quark interaction for the most poorly understood regime of Quantum Chromodynamics (QCD), the confinement regime. This proposal is part of a general program which intends to significantly improve our knowledge of proton and neutron electroproduction cross sections. The amplitudes extracted from the measurements will provide data to test models which attempt to describe the physics of quark binding. Some examples of these models include harmonic oscillator potential models, bag models, diquark pictures, and Skyrme models. The general introduction to this set of proposals has demonstrated the considerable potential for interesting results from these experiments. This section will focus on a measurement designed to study the longitudinal transition amplitude for the $S_{11}(1535)$ through its decay to ηp. This proposal is strongly tied to measurements of the cross section in the same mass range and with the more general goal of studying the entire second resonance region, a subject that has been presented in a previous section. That experiment will measure predominantly transverse processes; the main goal of this experiment is to study the same resonances in more detail through their longitudinal excitation. For a general overview of the kinematics and the notation used to express the cross sections and multipoles, the reader is referred to for example, the cross sections in Bartl et al.[1]

The $S_{11}(1535)$ is one of the most strongly excited and well–studied resonances. Its mass, 1.535 GeV/c^2, puts it in the second resonance region, just above the $P_{11}(1440)$ or Roper resonance and the $D_{13}(1520)$. A summary of the properties of the $S_{11}(1535)$ can be found in Table 1. As a dominant resonance, the $S_{11}(1535)$ plays an important role in the overall program and should serve as a stringent constraint on theory.

It also has a few striking physics characteristics. The decay branch to the ηp channel is unusually large, about an order of magnitude higher the typical value of a few percent. The S_{11} also has a total form factor that falls off much slower with Q^2 than other resonances,[2] a property that remains an unexplained feature [a]. A strong longitudinal $S_{11}(1535)$ amplitude was proposed a decade ago as an explanation for the slow Q^2 falloff since it must vanish as $Q^2 \rightarrow 0$. Two previous experiments determined the ratio of longitudinal to tranverse cross sections (σ_L/σ_T) called R.[3,4] The results at $Q^2 = 0.4$, 0.6, and 1.0 (GeV^2) were 0.23$\pm$.14, 0.25$\pm$.23, and -.013$\pm$.16,

[a] See also the earlier sections that discuss cross section measurements for the second resonance region.

	$S_{11}(1535)$	proton	η
spin	1/2	1/2	0
mass (MeV/c^2)	1535	938	549
width Γ	150 (MeV/c^2)		1.05 (keV/c^2)
charge	0 (+1)	+1	0
isospin	1/2	1/2	0
parity	-1	+1	-1
baryon no.	1	1	0
strangeness	0	0	0
quark content	udd,(uud)	uud	$u\bar{u}+d\bar{d}$
N (SU(6),L)	1(70,1)	0(56,0)	
wave function	$1S^2 1P$	$1S^3$	
decay	$N\pi$ 40% $p\eta$ 50%		$\gamma\gamma$ 38.9% $3\pi^0$ 31.9% $\pi^+\pi^-\pi^0$ 23.7% $\pi^+\pi^-\gamma$ 4.91%

Table 1: General characteristics of the S_{11}, proton and η

respectively. Although the longitudinal strength is nonzero, it cannot be the entire explanation.

From the experimental point of view, the large partial decay width of the $S_{11}(1535)$ to the ηN channel (about 50%) has been exploited to separate its contribution to the cross section from both the other resonant contributions and non-resonant background contributions. For electroproduction of the $S_{11}(1535)$ on a proton target, a proton and the electron detected in the final state can be used to construct a missing mass for the unmeasured particles in the final state. A simulated missing mass spectrum for the CLAS detector is shown in Figure 1. The peak at the η mass cleanly identifies the ηp channel. Identifying the ηN channel using missing mass has previously been shown to be an effective method for isolating the $S_{11}(1535)$.[3] Analysis of η production data[4, 2] has required only a small contribution from P partial waves (e.g., less than 2% of σ_{TOT}[2]) and very little non-resonant S wave production (e.g., less than 5% of σ_{TOT} at the $S_{11}(1535)$ peak[2] for Q^2=2 GeV^2). For the measurement proposed here, a better understanding of the characterization of ηN channel in terms of resonant and non-resonant contributions will be required.

The ηN channel is also of general theoretical interest. A recent calculation of the non-resonant processes has attempted to describe η photoproduction (Q^2=0) within the framework of an effective lagrangian theory.[5] The results of those calculations raise some interesting questions about the proper formulation of this process and demonstrate how poorly the process is understood. A review of the role of the ηN channel in electro and photoproduction by Tabakin et al.[6] also emphasizes the need for a complete description.

The goal of this proposal is to extend the meaurements of the longitudinal cross section down to a Q^2 of 0.1 GeV^2 and up to a Q^2 of 2.0 GeV^2 with an improvement in the error of a factor of 4.

MEASUREMENT

A super-Rosenbluth separation will be employed to extract the longitudinal σ_L and transverse σ_T cross sections. The ratio of these cross sections R does not require absolute normalization and can be measured to a higher precision than the individual cross sections. Throughout this section those errors not specifically associated with an individual cross section should be assumed to refer to R. The form of the single meson production cross section for unpolarized beam and target is[1]

$$\frac{d\sigma}{d\Omega_\pi^* d\Omega_{e'} dE'} = \Gamma(\epsilon)\frac{d\sigma}{d\Omega^*}$$

where Γ is the transverse virtual photon flux and with

$$\frac{d\sigma}{d\Omega^*} = \sigma_T + \epsilon\sigma_L + cos(2\phi^*)\sigma_{TT} + \sqrt{\frac{1}{2}\epsilon(1+\epsilon)}\sigma_{LT}.$$

Measurements of the cross section will be performed at different electron scattering angles and with different incident beam energies in order to vary ϵ. The measured cross sections at fixed values of Q^2 and W will have different longitudinal strengths due to the varying ratio of the longitudinal to transverse virtual photon flux ϵ with the electron scattering angle (θ_e). There is also a dependence in the above cross section on the out-of-plane angle ϕ^* due to the interference of the longitudinal and the transverse photons. The interference terms in the cross section σ_{TT} and σ_{LT} will be simultaneously measured in the CLAS detector. Note, however, that in the case of a pure ηp S wave final state the two interference cross sections (σ_{TT}, σ_{LT}) are zero. The phi dependence may therefore be used either as a test of S wave dominance or a test of the CLAS acceptance. In order to separate the cross section into the parts shown above, a precise measurement both of the total cross sections and scattering variables such as the direction and magnitude of the virtual photon momentum is required. The scattering variables are used to calculate multiplicative factors like Γ and to determine Q^2 and W for each measurement so that the amplitudes are extracted from the cross sections with minimal error.

Rosenbluth separations are routinely performed in electron scattering experiments. The method has been succesfully applied in inclusive scattering measurements in a similar kinematic region as we propose here to obtain R (σ_L/σ_T) at the level of 20%.[7] Since R is about .1-.2, the challenge is to control the errors that contribute to the uncertainty in the total cross section and the errors that enter when calculating the scattering variables for each measured cross section point. Our goal is to reduce uncertainties in any experimentally measured quantity to 1% or less, so that the total uncertainty in the cross section will not exceed 3%. Some of the systematic errors are expected to be controlled at the .1% level. The key to obtaining this kind of precision is finding calibrating reactions that measure the response of the detector. The CLAS detector is ideally suited for calibration with a set of specific reactions because it can simultaneously measure a large number of different processes. The trigger logic for the detector has the ability to select regions in angle and momentum and to prescale triggers. Several examples of calibrating reactions have been suggested in the proposal designed to study the multipole amplitudes in the $\Delta(1232)$ region. We reiterate some of these ideas here.

1. Elastic and inclusive ep scattering will be measured in order to monitor and calibrate the detector acceptance.

2. Inclusive ep scattering will be used to check detector uniformity in the azimuthal plane since no dependence on ϕ is allowed.

3. Missing mass distributions will be measured for reactions involving $n\pi^+$, $p\pi^0$ and $p\eta$ in the final state. Since the pion and eta masses are very well known, a measurement of the masses checks angle and momentum reconstruction for each event.

4. Two particle final states will be monitored. Momentum conservation forces these particle to lie in a plane. The ability to measure this planarity tests angle

calibrations. Other reactions with kinematic constraints will be similarly used.

We want to emphasize that these measurements are limited not by resolution, but by the absolute calibration of the angles and momenta, by uncertainties in acceptance and efficiencies and by normalization errors from, for example, target densities. After the CLAS detector is better understood, it will be capable of performing measurements of this caliber.

Two other sources of error that have not yet been discussed but can severly limit the precision of a measurement are the pion contamination at large angles and the radiative corrections. The design of the CLAS detector has directly addressed the problem of pion/electron separation. With the combined use of the dE/dx from the wire chambers, the light deposited in the threshold Cherenkov detectors, and the energy deposition and longitudinal shower development in the electromagnetic shower counter, misidentification of pions should not produce an error larger than about 1% in the measured cross section.[8] Radiative corrections are normally limited by theoretical uncertainties and by the kinematic range of the data set. Analysis of inclusive electron-proton scattering performed at SLAC have demonstrated that with care radiative corrections can be made so as not to introduce more than a 1% error in R.[7] With the CLAS detector being used for a number of related experiments, there should be a significant number of measured cross section points which can be used for radiative corrections.

The CLAS detector also offers some advantages. For example, the cross section does not need to be extrapolated to the Q^2 and W point of interest since data is being measured at a wide range of Q^2 and W points for each value of ϵ. Also, the low rates at backward angle can be somewhat offset by measuring over a larger angular range while maintaining constant Q^2 and W binning.

4. Time estimates

The crossection will be meaured at several incident electron energies. In general the larger the ϵ range the more sensitive the meaurement. The range of ϵ is limited by rate, the CLAS acceptance, and the available beam energies. Table 2 lists some possible measurement points, the asociated ϵ values and the scattered electron's momentum and scattering angle for the highest value of Q^2 (Q^2=2) considered by this proposal and for the invariant mass of interest W=1.535. In order to make a preliminary time estimate we examine the measurement with incident beam energy of E_0=2.4 GeV. This will require the most beam time. The missing mass spectra shown in Figure 1 was simulated using the comupter codes CELEG[9] and FASTMC.[10, 11] The detector was set to have a magnetic field that bent the outgoing electrons toward the beam. This field gives the CLAS detector more acceptance for the larger electron scattering angles and for lower electron momenta. The number of event detected in the η missing mass peak was used to estimate running time for this point. In order to obtain a statistical error of 1% (10,000 counts) in an invariant mass bin of 50 MeV/c^2 and a Q^2 bin of 0.5 GeV^2 a measurement time of 120 hours is required.

E_0 GeV	θ_e degrees	E' GeV/c	ϵ
6.0	16.3	4.1	.90
4.0	28.0	2.1	.75
3.0	44.8	1.1	.52
2.7	55.7	.84	.40
2.4	76.1	.55	.23

Table 2: Electron kinematics for Q^2=2 GeV^2, W=1.535 GeV/c^2

More general comments on the results of simulations are discussed in connection with the proposal to study the second resonance region. As stated, the CLAS detector is close to the ideal detector for excitation of the S_{11}. It accepts a large part of the decay phase space for the important decay channels of the S_{11} and provides superb missing mass resolution and reasonable angle and momentum resolution. The complete measurement with several Q^2 values (Q^2= .1 to 2) and with intermediate values of ϵ to check for the proper dependence on ϵ should require a total of about 1000 hours. This does not include time for testing the calibratiion and monitoring procedure. This experience will be gained as the detector is used for other measurements.

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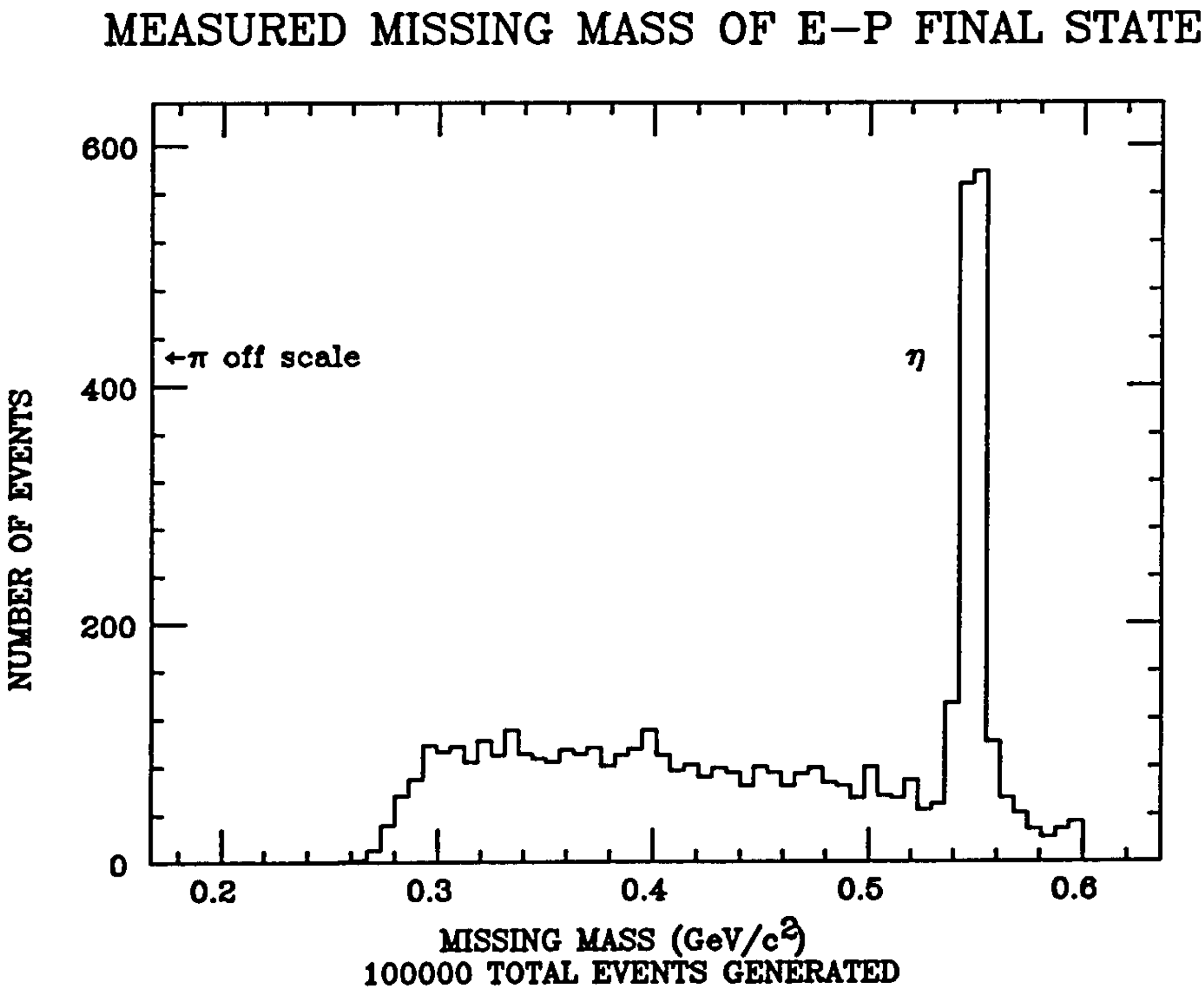

FIGURE 1. HISTOGRAM SHOWING MISSING MASS